Acid-Base Balancing

Primary Care Paramedicine

Module:11

Section:03

Acid-Base Balancing

- One of the most important balances in the body homeostatic mechanisms
  - Acids (proton donators)
  - Bases (proton acceptors)
  - Hydrogen ions (H^+)
  - Hydroxide ions (OH^-)

Acid / Base

- Hydrogen ion concentration
- Measured in moles/L (represented as pH)
- Acidity/alkalinity increases tenfold with every unit change

pH Chart

Neutral

7.35 – 7.45

(Human body)

Acid

↑ H^+

↓pH = Acidemia
(low blood pH)

Alkaline

↓ H^+

↑pH = Alkalemia
(high blood pH)

(6.7 to 7.9 compatible with life)

Le Chatelier's Principle

- Recall, that changes made to a reaction already at equilibrium will result in a shift to either the left or right to return the reaction to equilibrium

$$A + B \leftrightarrow AB + Heat$$

- Increase in concentration of reactants or products will cause shift away from the increase
- Decrease in concentration of reactants or products will cause a shift toward the decrease

Buffer systems

- Chemical (rapid)
  - Carbonic acid (bicarbonate buffering)
  - Phosphate buffering
  - Protein buffering
- Physiological (secondary)
  - Respiratory buffering
  - Renal buffering

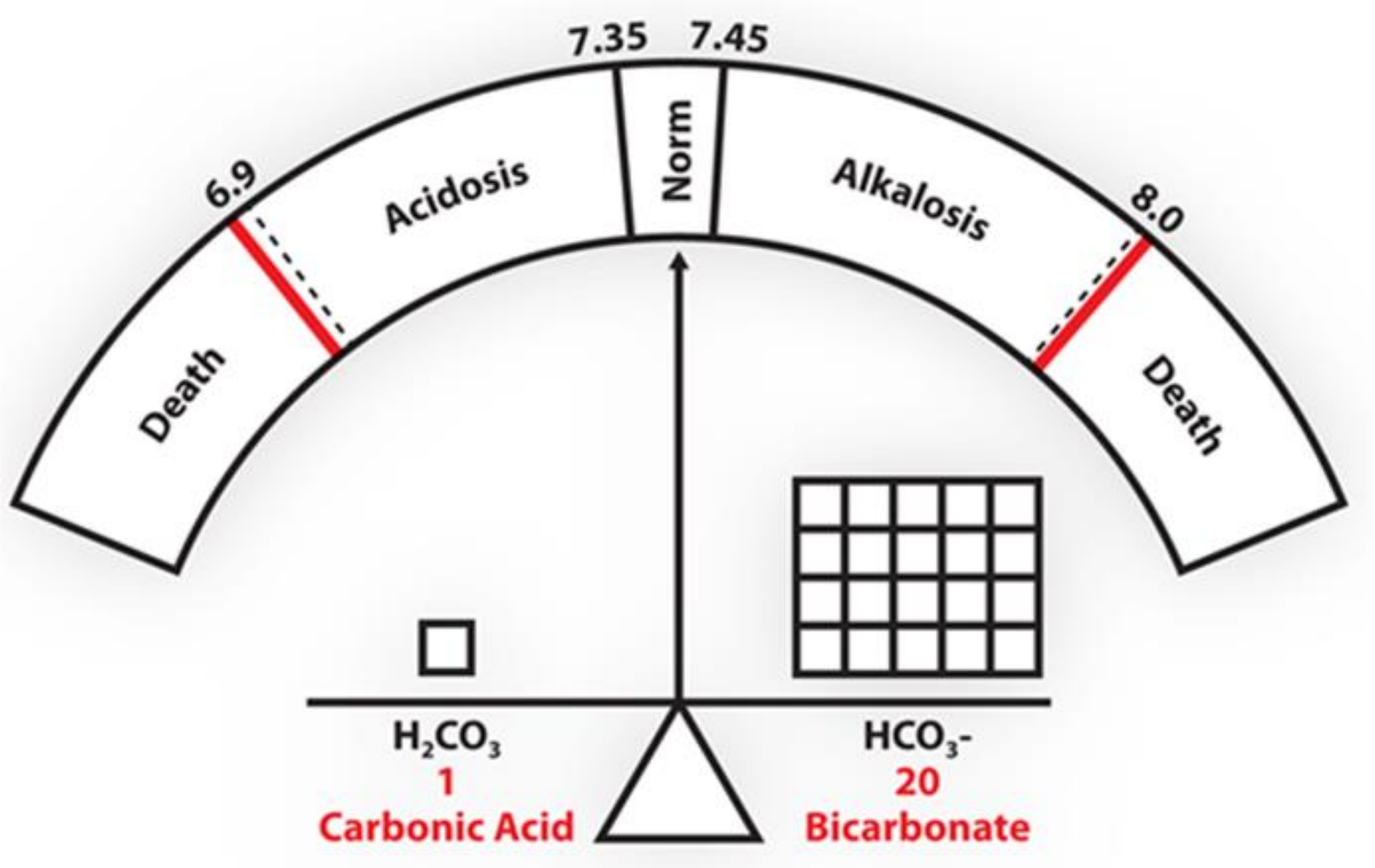
Carbonic Acid Buffer

- Normal carbonic acid to bicarbonate ratio is 1 – 20 = normal pH range
  - HCO_3^-, CO_2 and carbonic acid present in blood stream
  - HCO_3^- results from the transport of CO_2 in the blood
  - Carbonic anhydrase causes CO_2 to dissolve in water in the plasma to form carbonic acid (H_2CO_3)
  - H_2CO_3 breaks down into H^+ and HCO_3^-
- Increased H_2CO_3 = acidosis
- Increased HCO_3^- = alkalosis

Carbonic Anhydrase

$$CO_2 + H_2 0 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

Carbonic Acid Buffer



Protein Buffering

- Negative charges allow proteins to serve as buffers for alterations in $[H^+]$
- Primarily occurs intracellularly
  - Example:
    - In the tissues, CO_2 is high. Once this CO_2 enters the bloodstream, some is converted to Carbonic acid which then dissociates into Bicarb
      - This results in the release of H^+ into the blood
    - Hb then combines with H^+ to form a weak acid
    - At lungs Hb binds with O_2 causing the release of H^+
    - H^+ then combines with HCO_3^- ions to form H_2CO_3 which is converted back to CO_2 and exhaled

Phosphate Buffering

- Hydrogen Phosphate / Dihydrogen Phosphate equilibrium helps to buffer the intracellular fluid.

$$HPO_4{}^{2-} + H^+ \leftrightarrow H_2PO_4{}^-$$

- Example:
  - If extra H^+ ions enter the cell, HPO_4^{2-} can buffer the change and keep the pH within normal range
    - Results in increased $[H_2PO_4^-]$

Renal Buffering

- Recovery of bicarbonate and filtered into tubules
- Excretion of H^+ against a gradient to increase urine acidity
- Excretion of ammonium which carries H^+

Acid-Base Balancing

- Metabolic causes
  - HCO_3^- ion
- Respiratory causes
  - CO_2

Acid-Base Balancing

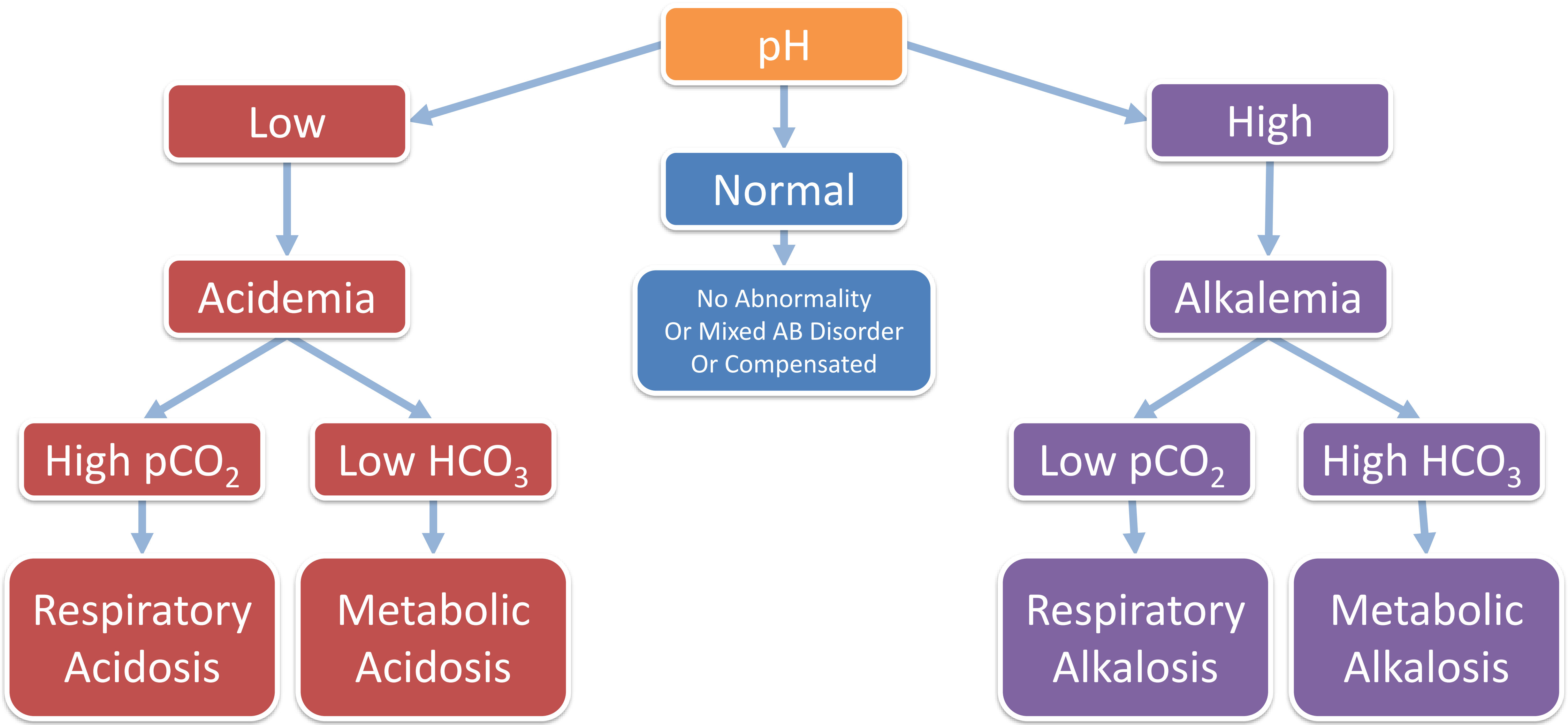
Acidosis

- Metabolic Acidosis
  - ↓ HCO_3^-
- Respiratory Acidosis
  - ↑ CO_2

Alkalosis

- Metabolic Alkalosis
  - ↑ HCO_3^-
- Respiratory Alkalosis
  - ↓ CO_2

Acid-Base Balancing



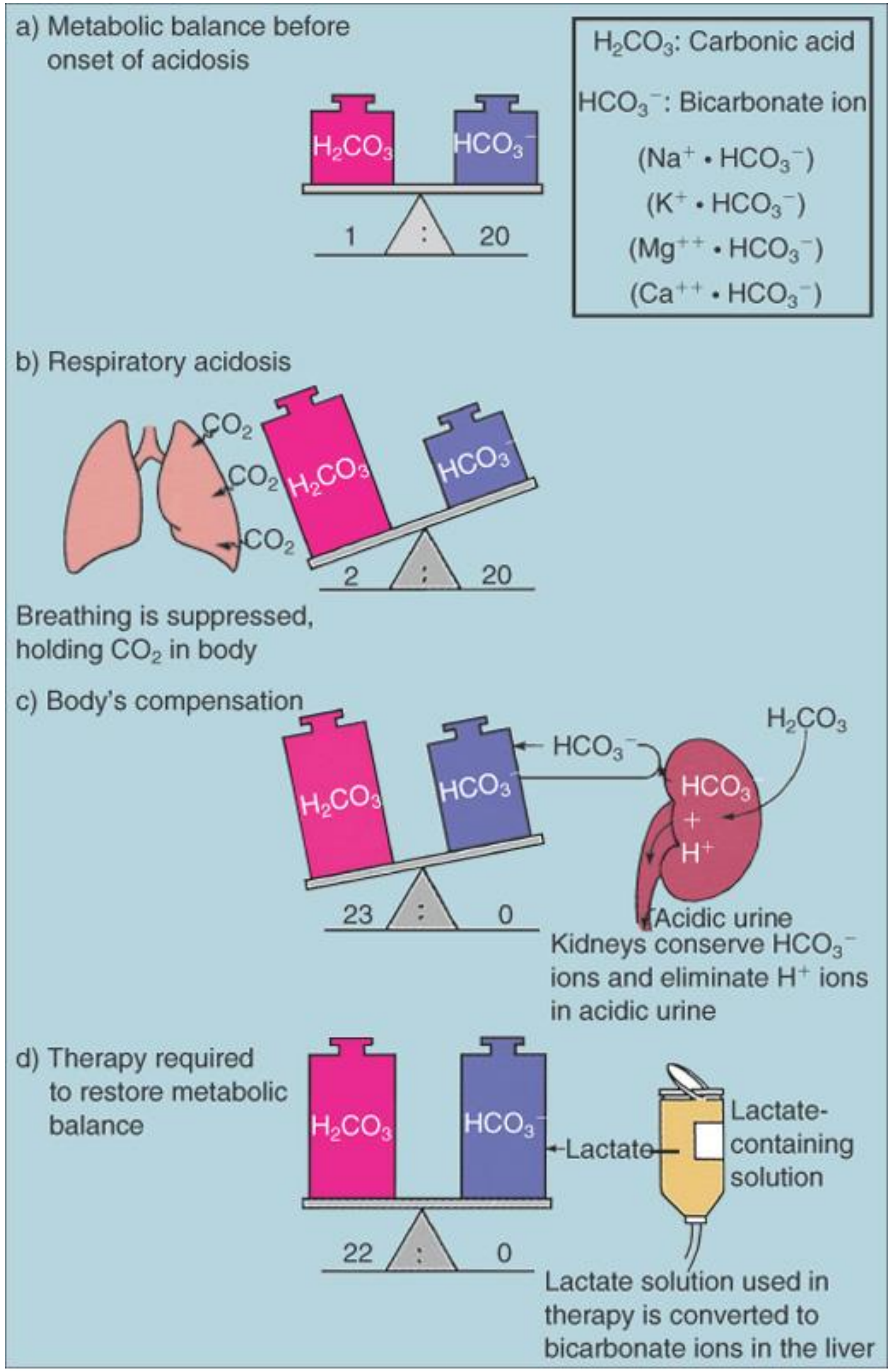
Case 1

- 25 year old
- Respiratory distress

Respiratory Acidosis

$$\uparrow CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow \uparrow H^+ + HCO_3^-$$

- Results from retained CO_2 and increased PCO_2
  - Depressed respiratory centre
    - Drug abuse, injury or disease
    - Anesthetics, sedatives, narcotics
  - Obstructive airways disease
    - Emphysema
    - Chronic Bronchitis
    - Asthma
    - Sever pneumonia
  - Blockages
    - Inhaled foreign object
    - Vomit
  - Bronchoconstriction (acute asthma)


a) Metabolic balance before onset of acidosis
H_2CO_3: Carbonic acid
HCO_3^-: Bicarbonate ion
($Na^+ \cdot HCO_3^-$)
($K^+ \cdot HCO_3^-$)
($Mg^{++} \cdot HCO_3^-$)
($Ca^{++} \cdot HCO_3^-$)
H_2CO_3
HCO_3^-
1 : 20
b) Respiratory acidosis
CO_2
CO_2
CO_2
H_2CO_3
HCO_3^-
2 : 20
Breathing is suppressed, holding CO_2 in body
c) Body's compensation
H_2CO_3
HCO_3^-
HCO_3^-
H_2CO_3
HCO_3^- + H^+
23 : 0
Acidic urine
Kidneys conserve HCO_3^- ions and eliminate H^+ ions in acidic urine
d) Therapy required to restore metabolic balance
H_2CO_3
HCO_3^-
Lactate
Lactate-containing solution
22 : 0
Lactate solution used in therapy is converted to bicarbonate ions in the liver

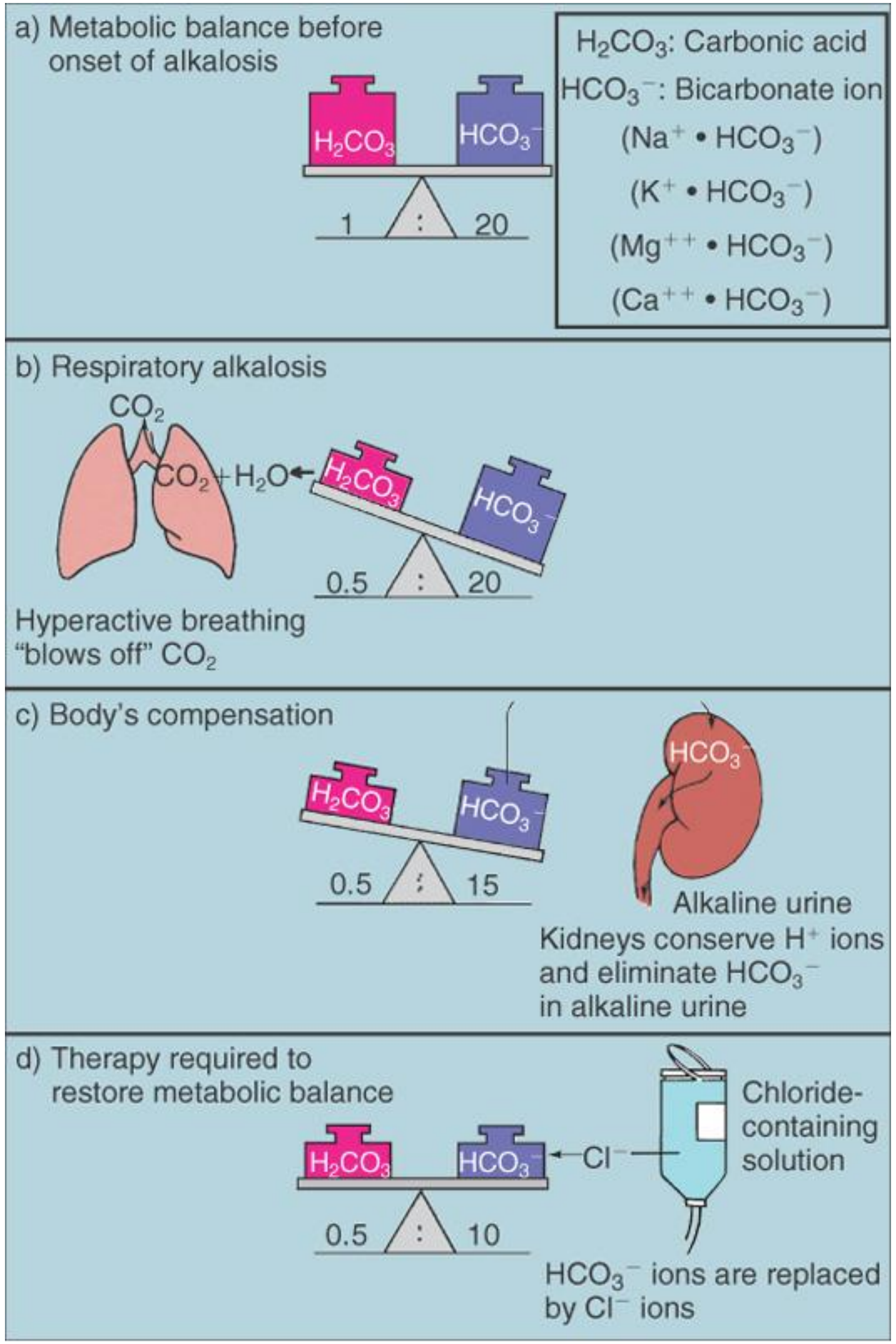
Cases

- 30 year old
- Palpitations with radiation to her hands
- Sister recently died due to Cancer

Respiratory Alkalosis

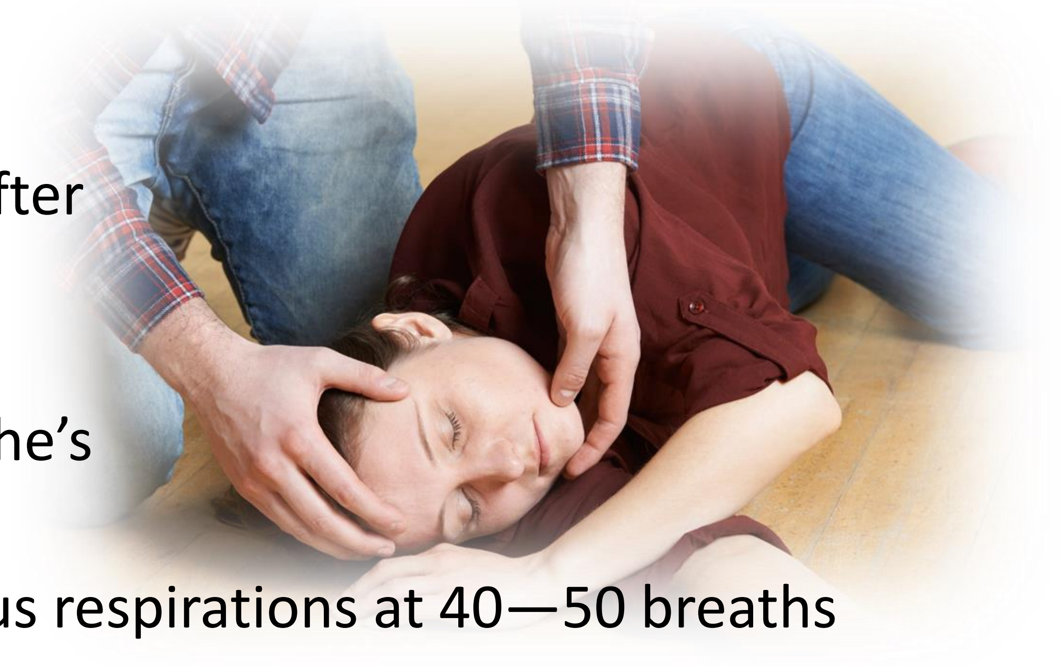
$$\downarrow CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow \downarrow H^+ + HCO_3^-$$

- Results from decreased PCO_2 through hyperventilation
  - Sepsis
  - Peritonitis
  - Shock
  - CO poisoning
  - Head injury
  - DKA



a) Metabolic balance before onset of alkalosis
H_2CO_3: Carbonic acid
HCO_3^-: Bicarbonate ion
($Na^+ \cdot HCO_3^-$)
($K^+ \cdot HCO_3^-$)
($Mg^{++} \cdot HCO_3^-$)
($Ca^{++} \cdot HCO_3^-$)
H_2CO_3
HCO_3^-
1 : 20
b) Respiratory alkalosis
CO_2
$CO_2 + H_2O$
H_2CO_3
HCO_3^-
0.5 : 20
Hyperactive breathing "blows off" CO_2
c) Body's compensation
H_2CO_3
HCO_3^-
0.5 : 15
HCO_3^-
Alkaline urine
Kidneys conserve H^+ ions and eliminate HCO_3^- in alkaline urine
d) Therapy required to restore metabolic balance
H_2CO_3
HCO_3^-
Cl^-
Chloride-containing solution
0.5 : 10
HCO_3^- ions are replaced by Cl^- ions

Case 1

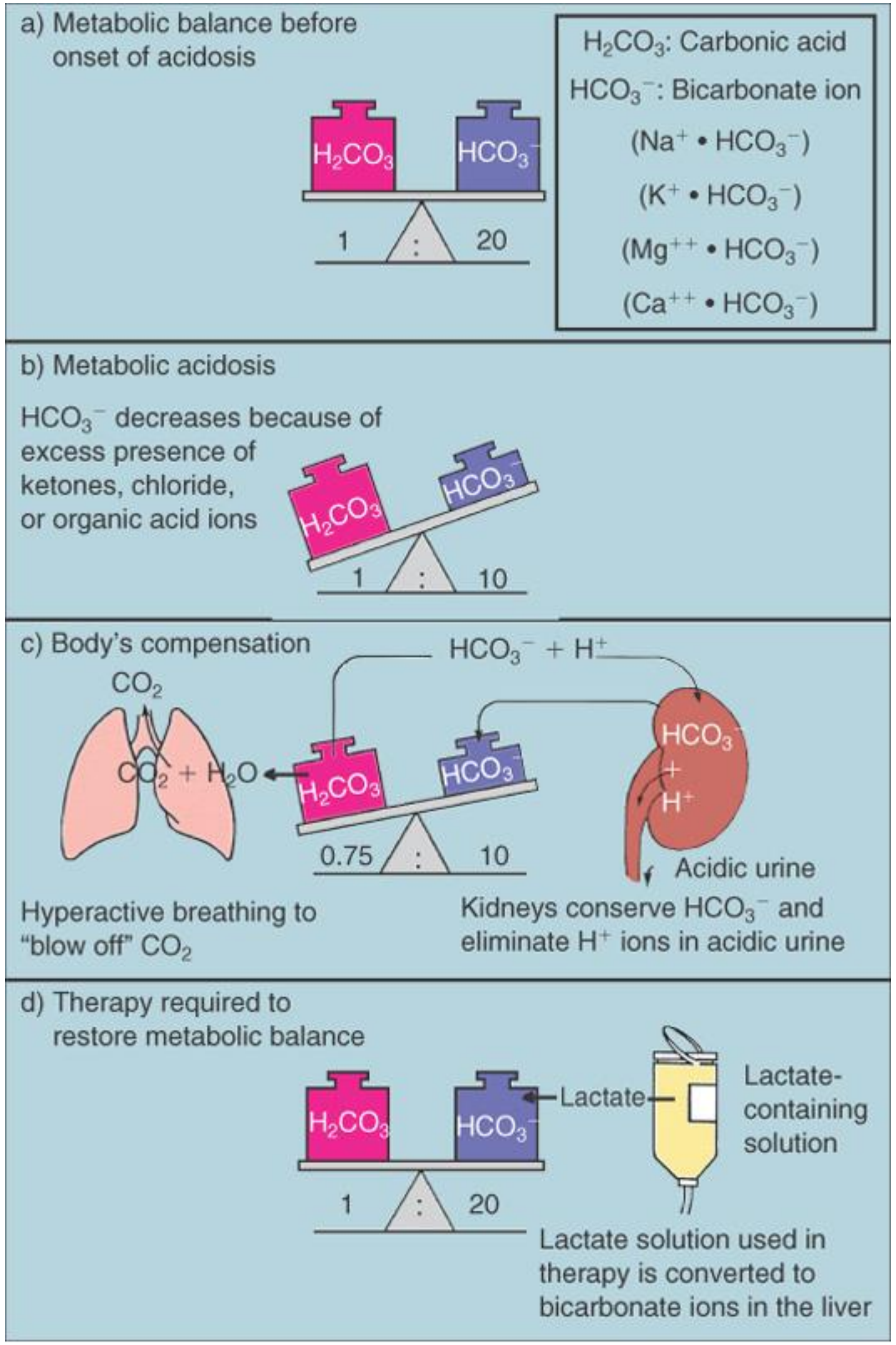


- A 34-year-old female with a history of diabetes is found unresponsive by a family member in bed after she missed work.
- Pt presents unconscious (Her neurological exam appears to be non-focal, her eyes open to pain. She's nonverbal and withdrawals from painful stimuli)
- Primary shows an open, clear airway; spontaneous respirations at 40—50 breaths per minute; and palpable radial pulses.
- GCS 7, Skin hot and dry, BP 132/78, HR 122 bpm, RR 48, SpO_2 98% on room air. Blood glucose level (BGL) is "HI" on glucometer. Secondary assessment is unremarkable with no signs of trauma or injury.

Metabolic Acidosis

$$\uparrow CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow \uparrow H^+ + \downarrow HCO_3^-$$

- Caused by excessive accumulation of acid or deficiency in base
- Affects the bicarbonate side of equation
- Excessive acid production = bicarbonate buffer consumption
- Common Types:
  – Lactic acidosis
  – Diabetic ketoacidosis
  – Renal failure
  – Ingestion of toxins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($K^+ \cdot HCO_3^-$)
($Mg^{++} \cdot HCO_3^-$)
($Ca^{++} \cdot HCO_3^-$)
H_2CO_3
HCO_3^-
1 : 20
b) Metabolic acidosis
HCO_3^- decreases because of excess presence of ketones, chloride, or organic acid ions
H_2CO_3
HCO_3^-
1 : 10
c) Body's compensation
$HCO_3^- + H^+$
CO_2
$CO_2 + H_2O$
H_2CO_3
HCO_3^-
0.75 : 10
HCO_3^-
+
H^+
Acidic urine
Hyperactive breathing to "blow off" CO_2
Kidneys conserve HCO_3^- and eliminate H^+ ions in acidic urine
d) Therapy required to restore metabolic balance
H_2CO_3
HCO_3^-
Lactate
Lactate-containing solution
1 : 20
Lactate solution used in therapy is converted to bicarbonate ions in the liver

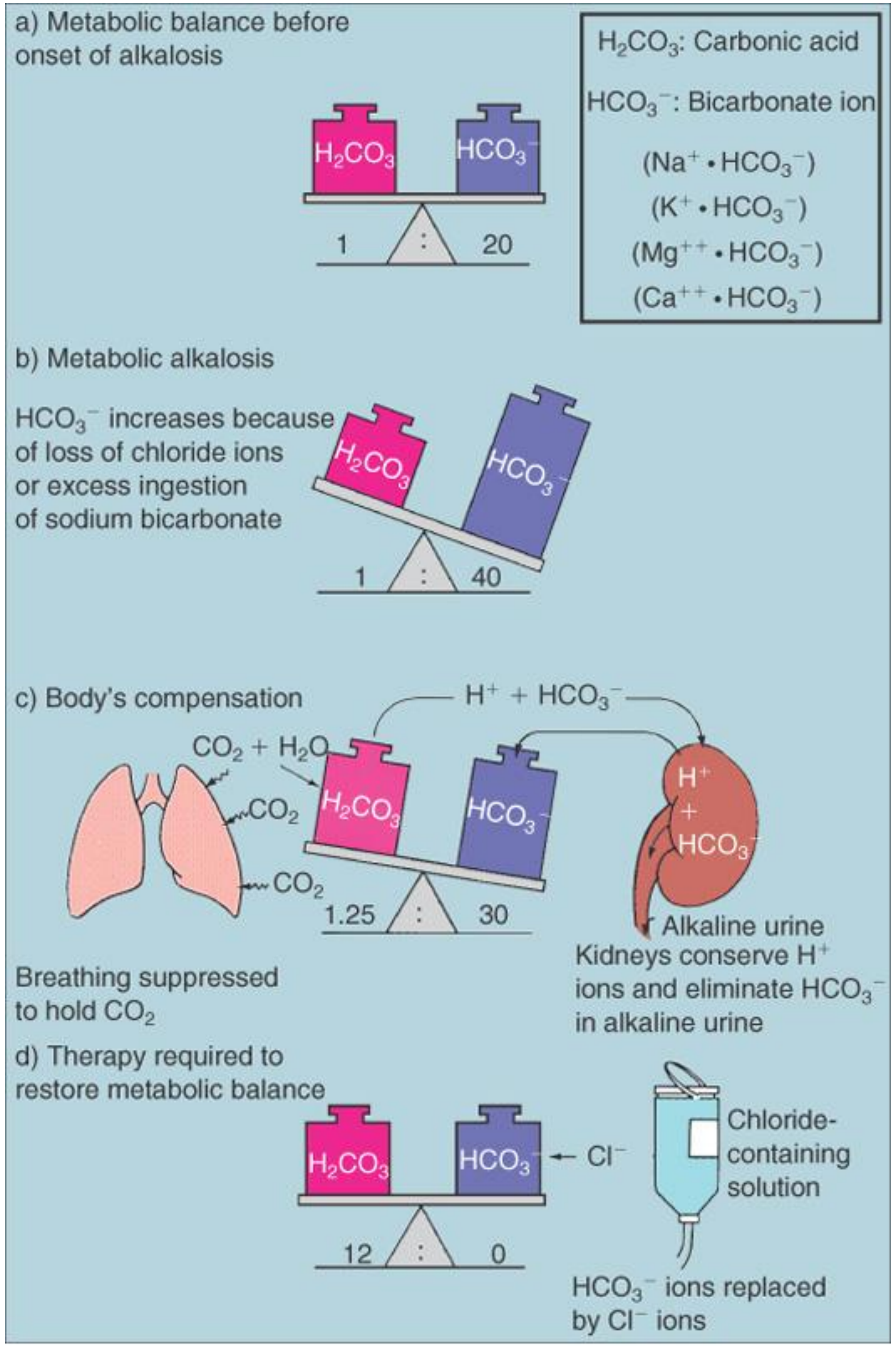
Case 2

- 56 year old
- Feeling unwell for 2 days
- Severe diarrhea

Metabolic Alkalosis

$$\downarrow CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow \downarrow H^+ + \uparrow HCO_3^-$$

- Rare
- Results from a loss of H^+
  - Primarily through the GI related to excessive antacid ingestion
  - Over administration of IV $NaHCO_3$
  - Over administration of diuretics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$(Na^+ \cdot HCO_3^-)$
$(K^+ \cdot HCO_3^-)$
$(Mg^{++} \cdot HCO_3^-)$
$(Ca^{++} \cdot HCO_3^-)$
H_2CO_3
HCO_3^-
1 : 20
b) Metabolic alkalosis
HCO_3^- increases because of loss of chloride ions or excess ingestion of sodium bicarbonate
1 : 40
c) Body's compensation
$H^+ + HCO_3^-$
$CO_2 + H_2O$
CO_2
CO_2
1.25 : 30
H^+ + HCO_3^-
Alkaline urine
Kidneys conserve H^+ ions and eliminate HCO_3^- in alkaline urine
Breathing suppressed to hold CO_2
d) Therapy required to restore metabolic balance
Cl^-
Chloride-containing solution
12 : 0
HCO_3^- ions replaced by Cl^- ions

Blood Gas Analysis

- Determines
  - Blood oxygenation
  - Acid-base balance
- Arterial blood used to identify respiratory function
- pH indicates acidosis/alkalosis
  - pCO_2 indicates presence/absence of respiratory component
  - HCO_3 indicates presence/absence of metabolic component

ABG

- Normal Ranges
  - pH 7.35 – 7.45
  - pCO_2 35 – 45 mmHg
  - pO_2 80 – 100 mmHg
  - HCO_3^- 22 – 26 mmol/L
  - BE -2 to +2 mmol/L
  - SaO_2 > 95 %
  - Anion Gap 8 - 16 mEq/L

Acid-Base Balancing

- Complete compensation (pH within normal limits)
- Partial compensation (pH near normal limits)
- Uncompensated (pH above or below normal limits)

Disorder	pH	H^+	Primary Disturbance	Compensatory Response
Metabolic Acidosis	↓	↑	↓ $[HCO_3^-]$	↓ pCO_2
Metabolic Alkalosis	↑	↓	↑ $[HCO_3^-]$	↑ pCO_2
Respiratory Acidosis	↓	↑	↑ pCO_2	↑ $[HCO_3^-]$
Respiratory Alkalosis	↑	↓	↓ pCO_2	↓ $[HCO_3^-]$

Rome

- **R**espiratory **O**pposite
- **M**etabolic **E**qual

Disorder	pH	H^+	Primary Disturbance	Compensatory Response
Metabolic Acidosis	↓	↑	↓ $[HCO_3^-]$	↓ pCO_2
Metabolic Alkalosis	↑	↓	↑ $[HCO_3^-]$	↑ pCO_2
Respiratory Acidosis	↓	↑	↑ pCO_2	↑ $[HCO_3^-]$
Respiratory Alkalosis	↑	↓	↓ pCO_2	↓ $[HCO_3^-]$